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United States Patent Application

Title: LINEAR SWITCH ACTUATOR

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FIELD OF THE INVENTION

This invention relates to microwave switch actuators and more particularly to a linear actuator for a microwave switch.

BACKGROUND OF THE INVENTION

Electro-mechanical microwave switches use electromagnetic actuators to change switch states by moving switch active elements such as RF reeds. Electro-magnetic switch actuators need to provide latching to allow the microwave switch to be powered up for only a short time period during switching. Intrinsic latching maintains the switch state during mechanical vibrations or shocks, ensures good electrical contact between the contacts, and provides extra reliability. Electro-magnetic switch actuators also need to have low mass and small volume since actuators typically account for more than one half of the switch mass. The inertia forces are proportional to the mass of the mobile armature, and therefore the amount of latching force/torque necessary to maintain the switch position increases with mass, requiring a higher active force and larger actuator.

Electromechanical switches employed in microwave communications are generally either switches with rotary actuators or switches with linear actuators. Linear electromagnetic actuators basically break down into three categories, namely electromagnetic actuators (that utilize the tractive force), voice coil actuators (that utilize the Lorentz force), and solenoid actuators (that utilize the reluctance force). There are several weaknesses associated with each of these types of linear actuators. Electromagnetic actuators, voice coil actuators and solenoid actuators do not have an intrinsic latching mechanism and accordingly an external separate latching mechanism is generally required. For electromagnetic actuators and solenoid actuators, since actuation is only

possible in a single direction, the use of either elastic elements (e.g. springs) or additional actuators are required to provide bi-directional functionality. Further, linear actuators generally exert their lowest force at the beginning of the stroke and their highest force at the end of the stroke. This is problematic since a large force is required at the beginning of the stroke in order to overcome latching forces. If actuators are simply made larger to overcome latching forces, the increased (i.e. very high) force at the end of the stroke results in excessively high mechanical impacts on switch contacts. Finally, voice coil actuators having a size that is compatible with microwave switch applications do not generally provide sufficient magnetic force for practical microwave switch applications.

More specifically, as shown in FIG. 1, electromagnetic actuators utilize an electromagnet **2** having stationary coils which attract a mobile armature **5**. The tractive force F that is associated with the electromagnet **2** is related to the magnetic flux Φ that exists within the air-gap of the electromagnet **2**, the magnetic permeability of free space μ_0, the area of pole regions A, the magnetomotive force of the coil mmf, the number of turns of the electromagnetic coil N, the electric current I through the electromagnet **2**, the magnetic reluctance R_{mk} for the circuit element k, the length L_{mk} of the circuit element k and the equivalent magnetic reluctance R_{me} of the circuit. The direction of the tractive force F generated does not depend on the direction of the current due to the fact the value of magnetic flux is squared in the force relation. Accordingly, a switch actuator that utilizes tractive force F is not bi-directional. Also, the magnetic force is minimal at the maximum gap since the magnetic reluctance is highest at the maximum gap resulting in lowest flux value. Conventional switch tractive force based actuators utilize armatures made of soft magnetic material that provide no intrinsic latching and must rely on external elements to provide latching. The tractive force based actuator disclosed in U.S. Patent No. 5,075,656 to Sun et al. utilizes an armature made out of a permanent magnet to achieve intrinsic latching and bi-directional motion. However, changing the armature from soft magnetic material to a permanent magnet results in a significant increase in the reluctance of the magnetic armature since $\mu_{PMAGNET} << \mu_{SOFT\ CORE}$. Accordingly,

the magnetic flux and the magnetic force will decrease significantly. For these reasons, these types of actuators are of very limited use and can be used only where an exceptionally short stroke is adequate.

FIG. 2 illustrates the basic operating principle of the Lorentz force upon which voice coil actuators are based. The interaction of a magnetic field B with the current I in a coil wire **3** generates the well-known Lorentz force. Either the coil wire **3** or the armature can be used as the mobile element within the actuator. The formulas listed in FIG. 2 that are used to calculate force F are based on the assumption that a charge q is traveling a length L of coil wire **3**. The direction of the magnetic force generated depends on the direction of the electric current I running through a coil wire **3**. Accordingly, the actuator is bi-directional. There is no intrinsic latching associated with a voice coil actuator based only on the Lorentz force since the force results only from interaction between the current I and the magnetic field B. For a constant current I, the force magnitude F is quasi-constant with the stroke. This is due to the fact that the force magnitude F depends only on magnetic flux density. The flux density remains constant because the magnetic flux direction is perpendicular to the direction of the stroke. The major disadvantage of a conventional voice coil actuator for microwave switch applications is that increasing the number of coil turns does not increase the magnetic force F generated. Rather, increasing number of turns increases the gap which in turn results in a decrease of the magnetic flux that intersects the coil turns. A voice coil actuator having a size and mass that is compatible with typical microwave switch dimensions can only generate a maximum force in the vicinity of 10 grams, which is not sufficient in practice for microwave switch applications.

Conventional solenoid actuators are normally constructed by winding a coil of wire **6** around a moveable soft iron core plunger **4** as shown in FIG. 3. Wire coil **6** is wound around plunger 4 and current is provided to the coil in such a direction such that the portion labeled as "A" represents current flowing out of the plane of the figure and that the portion labeled as "B" represents current flowing into the plane of the figure. Accordingly, the direction of the

magnetic flux Φ is shown by the arrowed line surrounding coil **6**. As shown, reluctance force F is exerted upon plunger **4**. The direction of the reluctance force F does not depend on the direction of the current since as with tractive force based actuators, the value of magnetic flux is squared in the force relation as shown. Accordingly, the solenoid actuator is not bi-directional. The direction of the force depends only of the direction that reduces the reluctance. The force is minimal at the maximum gap. Conventional solenoid actuators utilize soft magnetic material and as such possess no intrinsic latching. In an attempt to obtain bi-directional motion, solenoid actuators have been designed to utilize a permanent magnet for the plunger **4** as disclosed in U.S. Patent Application No. US 2002/0008601 to Yajima et al. However, in such a case, the reluctance of the plunger will increase significantly since $\mu_{PMAGNET} << \mu_{SOFT\ CORE}$ and the magnetic flux and the magnetic force will decrease causing the actuator to be inefficient. Another variant of the conventional solenoid actuator is the use of an additional elastic element (e.g. springs) to achieve the return stroke as disclosed U.S. Patent No. 6,133,812 to Magda or U.S. Patent No. 5,724,014 to Leikus et al. However, it is not desirable because the mechanical characteristics of elastic elements (e.g. springs) vary during the course of the actuator life and as such, important switch parameters, such as contact forces, latching stiffness etc. vary over time.

SUMMARY OF THE INVENTION

The invention provides in one aspect, a linear switch actuator for actuating a movable element within a microwave switch, said linear switch actuator comprising:

(a) a ferromagnetic shield having an interior region and first and second apertures;

(b) a magnetic coil having a longitudinal axis and positioned within the interior region of said shield and adapted to receive an energizing current;

(c) a moveable armature assembly adapted to be coupled to the movable element and positioned along the longitudinal axis of said coil and extending through the first and second apertures of said shield, said armature assembly being moveable between a first stroke end position and a second stroke end position, said armature assembly comprising:

(i) a ferromagnetic rod having a first end and a second end;

(ii) a first permanent magnet coupled to said first end of the rod and positioned within said first aperture, said first permanent magnet having a first pole orientation and being positioned substantially outside said shield at the first stroke end position;

(iii) a second permanent magnet being coupled to said second end of said rod and positioned within said second aperture and having a second pole orientation opposite to that of the first pole orientation, said second permanent magnet and being positioned substantially outside said shield at the second stroke end position;

(d) such that when said armature assembly is positioned at one of said first and second stroke end positions, the magnetic permeance associated with said armature assembly is maximized due to one of said first and second permanent magnets being positioned substantially outside said shield, resulting in bi-stable latching between said first and second stroke end positions; and

(e) such that when said energizing current is applied to said coil, said armature assembly moves between said first and second stroke end positions due to the combination of the force exerted on said armature assembly due to the magnetic interaction between said energized coil and the field associated with said first and second permanent magnets and the solenoid magnetic field associated

with said coil which reduces the magnetic permeance associated with said armature assembly.

Further aspects and advantages of the invention will appear from the following description taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 is a schematic diagram describing the operation of a prior art electromagnetic actuator;

FIG. 2 is a schematic diagram describing the Lorentz force upon which prior art voice coil actuators are based;

FIG. 3 is a schematic diagram describing the operation of a prior art solenoid actuator;

FIG. 4 is a cross-sectional view of the linear switch actuator of the present invention;

FIG. 5A is a schematic view showing the magnetic field distribution associated with the actuator of FIG. 4 when the actuator rod is in center position and the coil is not energized;

FIG. 5B is a schematic view showing the magnetic field distribution associated with the actuator of FIG. 4 when the actuator rod is in an actuator stroke end position and the coil is not energized;

FIG. 5C is a graph showing the magnetic latching force versus the positional displacement of actuator rod within the actuator of FIG. 4 over the course of an actuator stroke when the coil is not energized;

FIG. 6 is a schematic view showing the magnetic field induced by the coil of FIG. 4 in the ferromagnetic actuator rod alone when energized;

FIG. 7A is a schematic view showing the relationship between the magnetic field of the energized coil and the magnetic field associated with the actuator of FIG. 4 at the start of a stroke;

FIG. 7B is a schematic view showing the relationship between the magnetic field of the energized coil and the magnetic field associated with the actuator of FIG. 4 at the middle of a stroke;

FIG. 7C is a schematic view showing the relationship between the magnetic field of the energized coil and the magnetic field associated with the actuator of FIG. 4 at the end of a stroke;

FIG. 8A is a cross-sectional view of the linear switch actuator of FIG. 4 implemented within a conventional RF SPDT switch;

FIG. 8B is a top view of a prototype model of the implementation of FIG. 8A; and

FIG. 9 is a side view of the actuator associated with a prior art conventional microwave switch for comparison purposes.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 4 illustrates a linear switch actuator **10** built in accordance with the present invention. Specifically, linear switch actuator **10** includes a mobile armature rod **12**, permanent magnets **14a** and **14b**, an electromagnetic coil **16**, a shield **18** having ferromagnetic end plates **19**, and an armature piston **22**. Permanent magnets **14a**, **14b** are coupled to the ends of armature rod **12**, one at each end having a pole orientation as shown. Armature rod **12** is surrounded by coil **16**, and both armature rod **12** and coil **16** are encased within shield **18**. Current is provided to coil **16** in two directions which allows actuator **10** to operate bi-directionally. Linear switch actuator **10** utilizes the Lorentz force as well as associated magnetic reluctance (solenoid) forces that exist within the specific configuration of armature rod **12**, permanent magnet **14a** and **14b** and coil **16** of the present invention to provide actuation. Also, the magnetic

reluctance (solenoid) forces provide an intrinsic latching mechanism when coil **16** is not energized, as will be described.

Armature rod **12** is a cylindrical rod, preferably made from a soft ferromagnetic material with a high value of relative permeability, such as steel selected for high magnetic permeability, high saturation levels, and extremely low coercivity (e.g. nickel or cobalt steel alloys).

Permanent magnets **14a** and **14b** are coupled to the ends of armature rod **12** using epoxy bonding. Permanent magnets **14a** and **14b** are oriented such that like poles face each other. Specifically, FIG. 4 shows the pole orientation of permanent magnet **14a** to be S-N (S at the top, N at the bottom) and the pole orientation of permanent magnet **14b** to be N-S (N at the top and S at the bottom) such that the like poles N are facing each other. However, it should be understood that the permanent magnets **14a** and **14b** could also be oriented in the opposite fashion so that like poles S are facing each other. Therefore, permanent magnets **14a** and **14b** are orientated such that the generated magnetic bias is directed axially with respect to armature rod **12**. Permanent magnets **14a** and **14b** are preferably made from high-energy permanently magnetic materials such as sintered rare-earth magnets (e.g. samarium cobalt or neodymium iron boron alloys), although other permanently magnetic materials can be utilized. Accordingly, armature rod **12** and permanent magnets **14a** and **14b** together make up a moveable armature assembly that moves bi-directionally within coil **16** as will be described.

Coil **16** is a conventional annular electromagnetic coil wound around a conventional bobbin **24**. Coil **16** is oriented to be axially aligned with armature rod **12** and permanent magnets **14a** and **14b** along a longitudinal axis. Also, coil **16** is designed to surround a substantial amount of the combination of the armature rod **12** and permanent magnets **14a** and **14b** as shown in FIG. 4. Coil **16** is preferably made from standard magnetic wire (e.g. copper) of ultra fine gauge (e.g. AWG 40 or finer) although various metal materials and thicknesses may be utilized. Coil **16** is a single coil in the case where the associated

controller has bipolar drive capability. In the case of unipolar command, coil **16** is typically bi-filar magnet wire to allow for different current sense in the two wires.

Shield **18** encapsulates coil **16**, armature rod **12**, and at least a portion of permanent magnets **14a** and **14b**. The amount of permanent magnet **14a** and **14b** surrounded by shield **18** depends on the position of mobile armature rod **12** and associated permanent magnets **14a** and **14b** within shield **18**. Shield **18** is preferably made from soft ferromagnetic steels selected for high magnetic permeability, high saturation levels, and extremely low coercivity (e.g. nickel or cobalt steel alloys). Shield **18** includes ferromagnetic end plates **19** which are made from a magnetic material having a relatively high permeability (i.e. similar to that used within the rest of shield **18**). Ferromagnetic end plates **19** complete the magnetic return path for the magnetic field generated by permanent magnets **14a** and **14b**. Specifically, when permanent magnet **14a** or **14b** is positioned substantially on the outside of the associated magnetic end plate **19**, this ferromagnetic end plate **19** becomes the dominant return path and the resulting magnetic fields are largely "isolated" or "localized" from the armature rod **12**. Accordingly, shield **18** provides magnetic return path for the magnetic field generated by permanent magnets **14a** and **14b** in conjunction with armature rod **12**. The extremely low coercivity of both shield **18** and armature rod **12** permits actuator **10** to smoothly operate between stroke end states without any hysteresis-related impediments (i.e. associated with loss of permeance). Also, it should be understood that since it is desirable to pack as many coils in a space efficient manner between armature rod **12** and shield **18**, it is preferable for shield **18** to be substantially cylindrical and axially aligned with coil **16**. However, shield **18** could also be some other shape and/or orientated off-axis with respect to coil **16**, although such variations would result in actuator **10** having reduced efficiency.

Armature piston **22** is attached to the armature assembly and is used to actuate (i.e. apply pressure to) a movable element **17** within a Radio Frequency (RF) microwave switch (not shown) as will be further described. Armature piston **22** is shown coupled to permanent magnet **14a**, but it should be

understood that armature piston **22** could be coupled to the outside surface of either permanent magnet **14a** or **14b**.

Referring now to FIGS. 4, 5A, 5B, 5C, the intrinsic latching mechanism of linear switch actuator **10** will be described. Specifically, the magnetic characteristics that are produced when actuator rod **12** and permanent magnets **14a** and **14b** move within an un-energized coil **16** and shield **18** are shown. As shown in FIG. 5A, armature rod **12** is in the symmetrical center of its permitted travel path (i.e. it's center position) within actuator **10**. It should be noted that it is assumed that coil **16** is not energized (i.e. no current is flowing through coil **16**) for illustrative purposes. The resulting magnetic field distribution is shown. The magnetic flux emanating from permanent magnets **14a** and **14b** enters the ends of the armature rod **12** and subsequently exits the armature rod **12** radially toward the shield **18**. Shield **18** facilitates the return path through ferromagnetic end plates **19** to the opposite magnet poles within permanent magnets **14a** and **14b** by providing a low reluctance path.

In contrast, as shown in FIG. 5B, actuator rod **12** is shown at the end of its stroke. Again coil **16** is assumed not to be energized (i.e. no current is flowing through coil **16**) for illustrative purposes. In this asymmetric state, permanent magnet **14a** is substantially displaced outside the interior region of shield **18**. As a result of this, the magnetic flux associated with permanent magnet **14a** is largely localized and isolated from the armature rod **12**. Also, along with the upward movement of actuator rod **12**, permanent magnet **14b** has penetrated further into the interior region of shield **18**. As a result of the position of permanent magnet **14b** within shield **18**, the flux path from permanent magnet **14b** incorporates a significant portion of actuator rod **12** and shield **18**.

This in turn significantly improves the magnetic permeance (i.e. an increase in the ability of actuator **10** to conduct magnetic flux) within actuator **10**. The increase in magnetic permeance associated with penetrating permanent magnet **14b** exceeds the loss of magnetic permeance associated with isolated permanent magnet **14a** resulting in a net increase in overall magnetic

permeance. This means that near the end of a stroke, actuator **10** is in a lower energy state than it is near the middle of the stroke. Practically, this means that at the end of a stroke, a latching force (as shown in FIG. 5B) exists within actuator **10** to push the armature rod **12** and associated permanent magnets **14a** and **14b** away from the center of the shield which in turn holds armature rod **12** and associated permanent magnets **14a** and **14b** in place and the end of a stroke.

FIG. 5C is a graph that illustrates the latching force versus positional displacement of actuator rod **12** from a center position (i.e. center is when positional displacement is = "0") over an entire stroke. As shown, maximum latching force is exhibited at the two stroke ends as discussed above. Also, actuator rod **12** exhibits a bi-stable latching condition with a pronounced "over center snap" between positional displacements of -.005 and +.005 inches from center position. As shown in FIGS. 5A and 5B, comparable flux paths are produced and oriented radially through coil **16** (e.g. typically 0.2 Tesla in most embodiments). It should be understood that while the performance characteristics of the graph in FIG. 5C are associated with S-N pole orientation (S facing up and N facing down) of permanent magnet **14a** and pole orientation N-S (N facing up and S facing down) of permanent magnet **14b**, actuator **10** will operate similarly with a reverse pole orientations (i.e. N-S (N facing up and S facing down) polarity of permanent magnet **14a** and S-N pole orientation (S facing up and N facing down) of permanent magnet **14b**).

Now referring to FIGS. 4, 6, 7A and 7B, the magnetic characteristics associated with the movement of actuator rod **12** and permanent magnets **14a** and **14b** within an energized coil **16** will be described. Current is applied to coil **16** in a direction that is tangential to the surface of cylindrical actuator rod **12**. The result is a Lorentz force on coil **16** in a direction parallel to this cylindrical axis as shown. In reaction, an equal and opposite force is exerted on the permanent magnets **14a** and **14b** and armature rod **12** assembly. This reaction force constitutes a nearly constant force along the extent of the stroke.

Reversing the current direction in coil **16** reverses the force direction. This force represents part of the active actuation means.

FIG. 6 illustrates the magnetic field distribution induced by the energized coil **16** alone (i.e. for this illustration it is assumed that permanent magnets **14a** and **14b** have been replaced with steel and that coil **16** is energized). This illustration shows the typical solenoid magnetic field associated with coil **16**.

FIG. 7A illustrates the magnetic field distribution associated with actuator **10** at the start of an actuator stroke. At this point, armature rod **12** is latched in an upper position (as previously discussed in respect of FIG. 5B). The magnetic field created thereby will retain the permanent magnets **14a** and **14b** and armature rod **12** assembly in the latched (i.e. in this case, upper) position before the coil 16 is energized. When coil **16** is energized by current flowing in such a direction that the portion labeled as "C" represents current flowing into the plane of the figure and that the portion labeled as "D" represents current flowing out of the plane of the figure, the resultant Lorentz force associated with the radial flux through coil **16** exerts a force F downward on the permanent magnets **14a** and **14b** and armature rod **12** assembly as shown in FIG. 7A. Simultaneously, the solenoid magnetic field associated with coil **16** opposes the magnetic field within armature rod **12** that is generated by the penetrating lower permanent magnet **14b**, thus negating the high magnetic permeance path that created the latching force in the first place. Accordingly, the latching force described in respect of FIG. 5B is no longer present within actuator **10** and this in combination with the Lorentz force causes armature rod **12** and associated permanent magnets **14a** and **14b** to move downwards.

FIG. 7B illustrates the magnetic field distribution associated with actuator **10** at the middle of an actuator stroke when coil **16** is energized by current flowing in the same direction as shown in FIG. 7A. As armature rod **12** moves downwards, the lower permanent magnet **14b** moves away from the interior region of shield **18** and the upper permanent magnet **14a** starts to

penetrate the interior region of shield **18**. The influence of the lower permanent magnet **14b** that opposes the other flux sources within the armature rod **12** further diminishes. Although armature rod **12** is entirely within coil **16** throughout the stroke, the apparent penetration of armature rod **12** into coil **16** with respect to flux carrying capacity increases. Therefore, armature rod **12** behaves as a virtual solenoid. This solenoid like behavior operates in the same direction as the Lorentz force from the radial flux through the coil **16**. Accordingly, the motive force of linear switch actuator **10** is the combination of this solenoid like behavior of armature rod **12** and the resultant force F from the Lorentz force.

FIG. 7C illustrates the magnetic field distribution associated with actuator **10** at the end of an actuator stroke when coil **16** is energized by current flowing in the same direction as shown in FIG. 7A. The flux from the lower permanent magnet **14b** is largely suppressed (i.e. isolated and localized from actuator rod **12**) and the portion of the armature rod **12** within coil **16** contains flux in a single direction over the length of coil **16** as shown. The magnetic field created thereby will retain the permanent magnets **14a** and **14b** and armature rod **12** in the end actuator stroke position until the electric current is disconnected from coil **16**. Upon removal of electric current from coil **16**, the permanent magnets **14a** and **14b** and actuator rod **12** remain latched in the end actuator position in accordance with the latching mechanism as previously described.

The inventors contemplate that the thrust of linear switch actuator **10** is approximately 40% larger than the thrust associated with a conventional voice coil actuator of similar size that only harnesses the Lorentz force. In addition, a conventional voice coil actuator requires alternate latching means for switch application. Increasing the number of turns of the coil within the actuator does not have the same effect as in the case of voice coil actuators, because most of the coil generated magnetic flux is oriented along the armature axis and as such its flux density is less dependent of the coil thickness. Similarly, it is also contemplated that linear switch actuator **10** is advantageous over solenoid actuators in view of the fact that solenoid actuators are typically weak at start of a stroke and require additional means for latching and return stroke.

FIGS. 8A and 8B illustrate linear switch actuator **10** implemented within a conventional Radio Frequency Single Pole Double Throw (RF SPDT) switch **25**. Specifically, linear switch actuator **10** can be used within SPDT switch **25** to simultaneously actuate both RF reeds **30a** and **30b** as will be described. As shown in FIG. 8A, SPDT switch **25** contains RF components, an actuator (e.g. linear switch actuator **10**) and a telemetry/command interface components. The RF components include RF reeds **30a** and **30b**, ferromagnetic spring **35**, RF probes **37**, RF reed pistons **39a** and **39b**, RF reed magnets **44**, a RF channel, a RF housing **40**, and a RF cover **42**. The telemetry/command interface components include a telemetry printed circuit board (PCB) **50** and a telemetry relay **52**. This contains a magnetic SPDT relay actuated, without mechanical contact, by the corresponding actuator magnet and provides the position indication. The output can be as bi-level, resistive or both. Actuator **10** is attached to SPDT switch **25** by coupling shield **18** at one end to a support **46** preferably using epoxy bonding. Actuator piston **22** is also interlocked with ferromagnetic spring **35** as shown in FIG. 8A. Also, current is provided to coil **16** through wire **9** as shown in FIG. 8B. Ferromagnetic spring **35** is used as an interface between the two RF reeds **30a** and **30b**. The mechanism for latching the RF reeds **30a** and **30b** is provided by the internal latching of linear switch actuator **10**.

As conventionally known, a coaxial waveguide path is in the transmission state when a RF reed **30a** or **30b** is moved away from the ground plane and into contact with the RF probes **37**. When RF reeds **30a** or **30b** are in contact with RF probes **37**, a continuous coaxial transmission line exists between the associated RF probes **37**. The path geometry has been designed to provide an input impedance of 50 ohms. The waveguide path is in the non-transmitting state when a RF reed **30a** or **30b** is pulled against the ground plane (i.e. either against RF cover **42** or RF housing **40** as appropriate). In this state a waveguide transmission line now exists between the two corresponding RF probes **37**. The geometry of the waveguide has been designed so that the cut-off frequency is much higher than the operating frequency of the device. Thus a high level of

isolation exists between the two ports associated with a non-transmitting path. In each of the two distinct states of the switch, one RF path is in transmission while the other is in isolation mode.

SPDT switch **25** uses a ferromagnetic spring **35** to actuate RF reeds **30a** and **30b** (i.e. conductors) that connect or isolate the interface RF probes **37**. Switch actuation is accomplished by supplying SPDT switch **25** with a fixed length DC command pulse, after which SPDT switch **25** remains in a latched position without the application of any electrical current. When the actuator coil **16** is energized with a given polarity, actuator piston **22** is moved downwards under the action of the various magnetic forces described above. Correspondingly, ferromagnetic spring **35** pushes the RF reed pistons **39a** and **39b** downwards until RF reed **30a** associated with the shorter RF reed piston **39a** is in contact with RF probes **37** and the RF reed **30b** associated with the longer RF reed piston **39b** is grounded on RF housing **40**. In this position, even after the DC pulse is removed, a latching force exists pushing RF reeds **30a** and **30b** against RF probes **37** and RF housing **40**, respectively without any need for any electrical input.

When actuator coil **16** is energized with opposed polarity, a force having opposite direction is produced and actuator piston **22** moves upwards. The ferromagnetic spring **35** attracts the reeds permanent magnets **44** which in turn move the RF reeds **30a** and **30b** in the opposite direction until the RF reed **30a** associated with the shorter RF reed piston **39a** is grounded on RF cover **42** and the RF reed **30b** associated with the longer RF reed piston **29b** is in contact with the corresponding RF probes **37**. In this position also, after the DC pulse is removed, there is a latching force pushing the RF reed **30a** against the RF probes **37** and grounding RF reed **30b** against RF housing **40** without any need for an electrical input.

Accordingly, the RF components comprise two sets of reed/piston assemblies (each set comprising a RF reed piston **39a/39b** and an RF reed **30a/30b**) that define the two unique RF configurations as discussed above.

These RF reeds **30a/30b** are moved in and out of the waveguide paths **41** (i.e. RF channel) in the RF housing **40** via the interaction between permanent magnets **44** attached to RF reeds **30a/30b** and the ferromagnetic spring **35** connected to actuator piston **22**. RF housing **40** contains RF channel **41** and RF cover **42** contains the bores in which the above-noted reed/piston assemblies move. Dielectric guide-pins (not shown) are installed into the RF channel **41** to prevent RF reeds **30a** and **30b** from making electrical contact with the sides of RF channel **41**. RF cover **42** completes the waveguide path.

FIG. 8B illustrates a prototype of an implementation of linear switch actuator **10** within SPDT switch **25** that the inventors have built and tested. It should be understood that FIGS. 8A and 8B illustrate just one example implementation of linear switch actuator **10** within the particular RF reed structure of the RF SPDT switch **25** and that linear switch actuator **10** can be used to actuate various RF reed structures within many other types of RF switches such as T-switches, transfer (C-) switches, and Single Pole n Throw (SPnT) switches, switch matrices, redundancy switch configurations (i.e. redundancy rings) etc.

As an illustration of the substantial reduction in component complexity, it is worthwhile comparing FIG. 8A to FIG. 9. FIG. 9 illustrates the components of a conventional microwave switch **60**. In order to achieve switching, conventional microwave switch **60** requires two electromagnet actuators **62**, a latching magnet **64**, bearings **66** and springs **68**. This is in sharp contrast to the use of only one linear actuator **10** consisting of coil **16** and armature **12** within linear switch actuator **10** as described above.

As will be apparent to those skilled in the art, various modifications and adaptations of the structure described above are possible without departing from the present invention, the scope of which is defined in the appended claims.